Sensitive new laser technique detects volatile organic compounds

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Researchers have developed a new way of operating miniature quantum cascade lasers (QCLs) to rapidly measure the absorption spectra of different organic molecules in the air simultaneously. The technique offers a sensitive method for detecting low concentrations of volatile organic compounds (VOCs), improving the ability to track how these compounds affect human health, industrial processes and ambient air quality. The new system also could improve the reliability of breath alcohol tests by more selectively distinguishing between ethanol and the other gases people exhale.

QCLs are made from multiple layers of semiconductors arranged to boost photon emissions by exploiting quantum effects. The researchers designed a QCL based setup that measures compounds absorbing electromagnetic radiation across a wide spectrum with a single laser, a task that would have previously required multiple lasers working together.

VOCs are commonly found in vehicle exhaust, solvents, building materials and many other products. They can be harmful to people and ecosystems, and they contribute to tropospheric ozone production and to global warming. Real-time methods to identify and track VOCs are important for pollution and climate researchers, public health organizations, manufacturers, first responders and shippers, among others.

The new system, based on an electrically tunable infrared laser with no mechanical parts, provides sufficient precision and scans a wide enough range of optical frequencies to simultaneously identify several species that are present and determine their concentrations. The Switzerland-based researchers, led by Lukas Emmenegger of Empa, a materials science and technology institute, will describe their novel method at The Optical Society's Optical Sensors and Sensing Congress, which will take place from 25-27 June in San Jose, Calif., during Sensors Expo 2019.

Opening narrow windows onto a broad spectrum

Unlike the task of detecting a single chemical compound, identifying the different species within VOCs requires dialing the QCL's optical output across a very broad range of frequencies. To accomplish this, the researchers used a relatively new type of QCL, optimized to be adjustable across a wider than usual emission frequency range, known as a Very Large Tuning QCL (QC-XT), and powered the device in an intermittent mode to maximize optical tuning and minimize the laser's energy consumption.

Then they introduced the main innovation of the new approach: By heating the front or back mirror of the laser with short pulses of electrical current, they found they could select the span of frequencies the laser would produce by the so-called Vernier effect. Using this approach, the setup essentially moves through several channels of observation along the molecule's absorption spectrum in which precise details can be measured and compared to known spectral features, offering nearly continuous coverage across a wide frequency range with great precision.

"The rapid switching between different channels of the QCL offers unprecedented real-time selectivity and sensitivity for the detection of VOCs," Emmenegger said.

"High-precision VOC measurements are currently dominated by classical methods, such as gas chromatography or mass spectrometry. Combining the high spectral resolution of well-established distributed-feedback QCLs with the multi-channel capacity of QC-XT may become a game-changer in the field of VOC analysis," Emmenegger added.

Fast and sensitive detection

This innovative analytical approach lends itself particularly well to quick recognition of broadly spaced spectral features of VOCs. To test the method, the team used their new setup to simultaneously measure the infrared spectra of a mixture of methanol, ethanol and acetaldehyde.

The demonstration showed that the method successfully distinguishes each molecular species from the others and is fast and sensitive. A round of measurements through six different spectral channels took a total of 18 milliseconds. While individual channels are scanned at very high spectral resolution within only 50 microseconds, most of the time is spent on adjusting the electrical heating of the laser components to select the next channel location along the spectra.

The system assessed molecular concentrations as low as 50 parts per million with a precision of 50 parts per billion. With further work, the researchers believe the system could achieve even greater sensitivity.

Improving breath analysis

In addition to being primed for an array of applications in environmental and occupational VOC detection, the new system could find application in medical breath analysis or to improve currently employed standards for the measurement of breath alcohol content.

In a paper published on 12 February in The Optical Society's journal *Optics Express*, the Empa team reports detection of airborne alcohol at concentrations as low as 9 parts per billion using a QCL. These results suggest that use of QCL laser-based spectrometers for breath alcohol analysis may offer a route to globally improved reliability and standardization of the world's most frequent forensic test, researchers say.

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